RESEARCH DEPARTMENT

IMAGE-TRANSFER STANDARDS CONVERSION

Report No. T-116

(1963/55)

C.B.B. Wood

D. Maurice

(D. Maurice)

This Report is the property of the British Broadcasting Corporation and may not be reproduced or disclosed to a third party in any form without the written permission of the Corporation.

IMAGE-TRANSFER STANDARDS CONVERSION

Section Title Page

SUMMARY 1

1. INTRODUCTION 1

1.1. The New Scanning Standard 1
1.2. Basic Forms of Standards Conversion Apparatus 2
1.3. Asynchronous Working. 2
1.4. Applications for the Image-Transfer Standards Converter 3
1.5. The Possibility of Improving Image-Transfer Standards Converters 3

2. THEORETICAL CONSIDERATIONS 4

2.1. General Performance Requirements 4
2.2. Portrayal of Moving Objects 4

2.2.1. Multiple Images due to Afterglow in the Display Tube 5
2.2.2. Multiple Images due to Incomplete Erasure in the Standards Converter Camera 7

2.3. 'Sticking' in the Image Orthicon 8
2.4. 'Photo-Signal' Effects 8
2.5. Vertical Resolution 9

2.5.1. General 9
2.5.2. 'Conversion in Pictures' 9
2.5.3. Vertical Aperture Correction 10

2.6. Noise 11
2.7. Optical Distortions 12

2.7.1. 'Background' 12
2.7.2. Cathode-ray Tube Flare 13

Section Title Page

3. AN APPRAISAL OF THE MOVEMENT PORTRAYAL PROVIDED BY EXISTING APPARATUS 13

3.1. Method of Measurement 13
3.2. Results 14
3.3. Comparison of Results 15

4. OBJECTIVE MEASUREMENTS OF CAMERA TUBES 16

4.1. General 16
4.2. Comparison of Performance 17

4.2.1. Sensitivity 17
4.2.2. Horizontal Resolution 19
4.2.3. Signal-to-Noise Ratio 20
4.2.4. Erasure of Redundant Information 20

5. OBJECTIVE MEASUREMENTS OF EXISTING DISPLAY TUBES 21

5.1. Measurement Methods 21
5.2. Afterglow 22
5.3. Phosphor Grain 23
5.4. Screen Brightness 25
5.5. Resolution 25
5.6. 'Sticking' in Display-Tube Phosphors 26

6. SUBJECTIVE TESTS OF STANDARDS CONVERSION ARRANGEMENTS 26

6.1. Method of Testing 26
6.2. Results 27

7. CONCLUSIONS AND RECOMMENDATIONS 29

7.1. Limits of Acceptable Performance 29

7.1.1. Movement Portrayal 30
7.1.2. Random Noise 30
7.1.3. Background 31
7.1.4. Resolution 31
7.1.5. Sensitivity 31
7.1.6. 'Sticking' 32

Section Title Page

7.2. General Recommendations 32

7.2.1. Camera Tubes 32
7.2.2. Display Tubes 33
7.2.3. Circuit Arrangement 33
7.2.4. Operational 34

8. ACKNOWLEDGEMENTS 34

9. REFERENCES 35

PRIVATE AND CONFIDENTIAL

November 1963

Report No. T-116

(1963/55)

IMAGE-TRANSFER STANDARDS CONVERSION

SUMMARY

This report contains an appraisal of the available means for converting television signals from one line scanning standard to another, the field frequencies being nominally equal.

Recommendations are made for some improvements which should be made to existing equipment and considerations are given for the design of new equipment.

1. INTRODUCTION

1.1. The New Scanning Standard

The authorization of a second television programme on 625 lines has thrown new emphasis on the need for improved means of standards conversion, principally from 625 lines to 405 lines. Certain features of the new system, notably that some of the transmissions are to consist of compatible colour television signals, necessitate the adoption of stable scanning frequencies and this in turn has repercussions on the means whereby conversion may be carried out from one standard to the other.

Eventually all television broadcasting in U.K. will be on 625 lines but a changeover of the existing programme to this standard must entail duplication on 405 lines for several years to provide an economical life for the many existing receivers capable of reception only on this standard. It is in this application that the most important use of standards conversion is envisaged since the obvious course to adopt in producing the same programme material on both 625 and 405 lines is to originate pictures in the studios on the former standard and to standards-convert these signals to 405 lines for the continuing service radiated in Band I. This means that receivers only able to make use of 405-line signals will receive the whole of their service from the output of a standards converter and, unless some substantial improvement in the performance of such devices can be obtained, they are likely to show an unwelcome fall in picture quality.

1.2. Basic Forms of Standards Conversion Apparatus

Existing standards converters operate on what has been termed the 'Image-Transfer' process. The basic form of this apparatus is such that the signals of the scanning standard to be converted are displayed as a normal image on a cathode-ray tube and the transfer is effected by means of a television camera which views this display and operates on the new standard (Fig. 1). A considerable effort is being made to develop a new form of standards converter[1,2] which operates without recourse to optical images. The incoming picture signals are fed into a multiplicity of electrical stores, each of which will contain the information of one picture element: the charges are then withdrawn from these stores at a rate appropriate to the outgoing scanning standard. In addition, a process of interpolation between vertically-adjacent elements of each incoming television field is carried out either by means of a delay line or by filter elements incorporated in the electrical stores. This new approach to the problem may well yield much superior results to those obtained with the present image-transfer standards converters. There seems, however, to be an instrumental limitation, due entirely to the volume of storage apparatus required, which precludes the possibility of employing this method for converting between television systems of differing field frequencies; the use of the line storage standards converter thus imposes the prerequisite that the fields of incoming and outgoing television systems have a precise phase relationship.

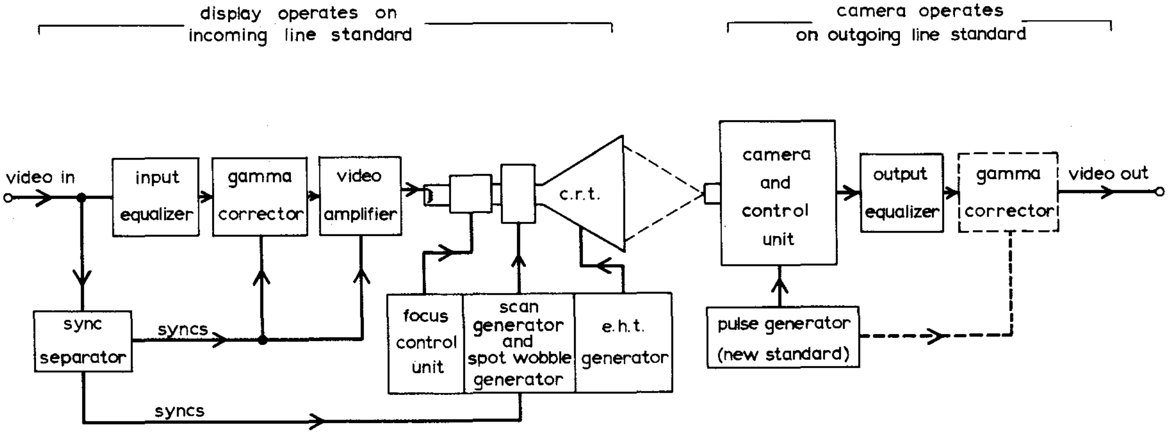


Fig. 1 - Block diagram of typical image-transfer standards converter

1.3. Asynchronous Working

For a variety of reasons, outside the scope of this report, there seems to be little likelihood of devising a method of colour television transmission in which the television fields may be made synchronous with the mains supply frequency. Hitherto the British television system has normally been operated in synchronism with the alternations of the electricity supply voltage in order that disturbances of the geometry or brightness of the picture (hum), due to power supplies derived from the mains, form a static pattern. Such a disturbance is known to be much less visible than one which moves steadily through the picture at a frequency which is the difference between that of the mains and of the television fields.

It has already been proposed[3] that the 625-line system shall be operated with stable scanning frequencies, i.e., not in synchronism with the mains supply. A 405-line transmission derived from a 625-line signal by means of a line-storage standards converter will therefore also be of stable field frequency and not in synchronism with the mains supply. Existing, non-switchable 405-line receivers have, in general, been designed on the assumption that the television fields will be in synchronism with the mains supply, so their resistance to hum disturbance is not very high and it is to be hoped that their numbers will have diminished considerably before the 405-line service becomes asynchronous.

The image-transfer standards converter can be made capable of conversion between television standards having widely different field frequencies.[4] With this device it would thus be a fairly simple matter to operate a 625-line system having stable scanning frequencies and yet achieve programme duplication on the existing 405-line system with the field frequency synchronized to that of the mains. The cost of doing so lies in the probable inferiority of the converted picture.

1.4. Applications for the Image-Transfer Standards Converter

The future usefulness of image-transfer standards converters would seem to depend on three main factors.

(a) The necessity for interchange of programme material between the two programmes operating on different standards ('diagonalisation') during the period before the complete duplication of BBC 1 programme on 625 lines and the consequent adoption of asynchronous working on 405 lines.

(b) Ability of the 405-line system to operate asynchronously. It might happen that the overall result of high-quality line-store standards conversion together with positional hum in the domestic receiver due to asynchronous working was found to be less acceptable to the viewer than the inferior image-transfer standards conversion displayed on a receiver operated with a field frequency locked to that of the mains supply.

(c) International Television Exchanges. For standards conversion between the North American television standard of 60 fields per second and the British 50 fields per second (625 lines or 405 lines) some form of image-transfer device is at present essential.

1.5. The Possibility of Improving Image-Transfer Standards Converters

There is sufficient likelihood of the image-transfer standards converter playing a useful part in future operations to have made it seem worth while to carry out an appraisal of the available apparatus and to consider where significant improvements might be made. The results of this investigation form the substance of this report.

It should be noted, however, that 60 to 50 fields-per-second standards conversion has been excluded from the considerations. The examination of component performance has been made with the assumption that field difference-frequencies seldom would exceed 0·25 c/s, i.e. one standard would be crystal-controlled while the other was locked to the electricity supply.

2. THEORETICAL CONSIDERATIONS

2.1. General Performance Requirements

The principal difficulty which confronts the task of standards conversion is that any degradation of the picture which it introduces is inevitably added to a picture which is already marginal in acceptability. Hence the signal-to-noise ratio, resolution and grey-scale accuracy required are generally higher than those necessary in picture originating equipment. Even more important, however, is the necessity to avoid further destruction of the illusion that the original scene is being viewed. The viewer is to some extent conditioned to accept a small image in black-and-white as being normal, and even low resolution and excessive random noise do not seem to the lay viewer to be particularly serious impairments, perhaps because their parallels in nature are poor visibility and rain, but geometric distortion of the image, a superimposed static pattern of blemishes and grain, or multiple image of a moving object are immediately recognized as unnatural and hence are unacceptable.

2.2. Portrayal of Moving Objects

One of the principal criticisms which have been made of existing standards converters concerns their ability to portray moving objects.

In the image-transfer method of standards conversion, each incoming television field is displayed on a cathode-ray tube. A television camera, viewing this display, stores the image until the 'reading' beam of the camera tube erases it in scanning the stored information at the new standard. This cycle of events differs somewhat from the case where a television camera views a normal scene, in that the light from the converter cathode-ray tube is not continuously present. A bright 'writing' spot traces the raster at the incoming scanning standard and it is only during the afterglow period of the phosphor of the cathode-ray tube that exposure of any point in the image to the television camera can take place. The relative field phase of the 'writing' beam in the cathode-ray tube with respect to the 'reading' beam in the camera tube can have an important significance in the appearance of the converted picture, as will be shown later.

All low-velocity camera tubes which integrate, up to the limit of their storage capacity, the light which falls on any point in the image throughout the interval between scans, may show 'trailing' or blurred images of moving objects. This effect is more familiar as that given by insufficiently short exposure in ordinary still photography, where the image of a moving object is seen to be 'smeared' along the direction of motion over a distance equal to that travelled during the exposure time. Given that the incoming fields are sharp (i.e. discrete images without 'blurring'), it will be seen that a standards converter cannot produce this effect in its own right. Each incoming field is displayed on the cathode-ray tube with the original movement 'frozen' and the converting camera sees only a series of static pictures. The output from the converting camera may, however, and unfortunately often does, shows remnants of preceding fields simultaneously with the current field and thereby portrays a moving object as a multiple image, each image being displaced from its neighbour by the distance travelled between successive fields.

There are several causes of multiple-imaging in an image-transfer standards converter and they are explained in the following sub-sections.

2.2.1. Multiple Images due to Afterglow in the Display Tube

All existing standards converters employ a display tube in which the afterglow of the phosphor has a substantially longer duration than that of the conventional receiver picture tube. Where the field repetition rate of the incoming television signal is not the same as that required in the converted pictures there is created either a surplus or deficit of fields, or parts of a field, in each single field scan period of the converter camera tube. If the afterglow of the display tube were short, some fields 'read out' by the standards converter camera would contain either two, or zero exposures depending on whether the duration of the converted field is longer or shorter than that of the incoming field. This is shown in Fig. 2 in which it will be seen that the display brightness at any point in the field is renewed as the scanning spot passes and then rapidly dies away. The field period of the standards-converted system is shown as of shorter duration than that of the incoming signal and at one particular phase relationship the camera has received no exposure at all. Similarly, an output field period longer than that of the incoming signal can embrace two full exposures from the short-persistence display tube. Either of these conditions would create in the converted signal a brightness variation at the difference frequency between the field repetition rates and would result in a bright or dark bar travelling vertically through the picture. Since the difference in field rates is small in the cases under consideration, say 0•25 c/s, the effect can be greatly mitigated by the use of a display having a longer period of afterglow.

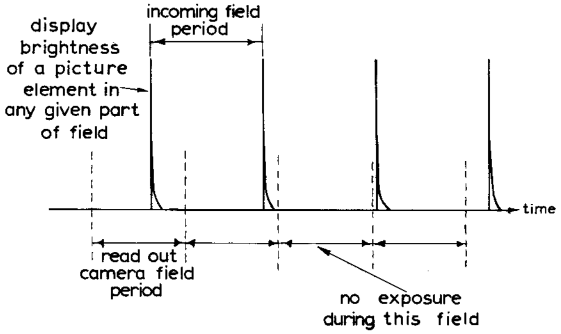
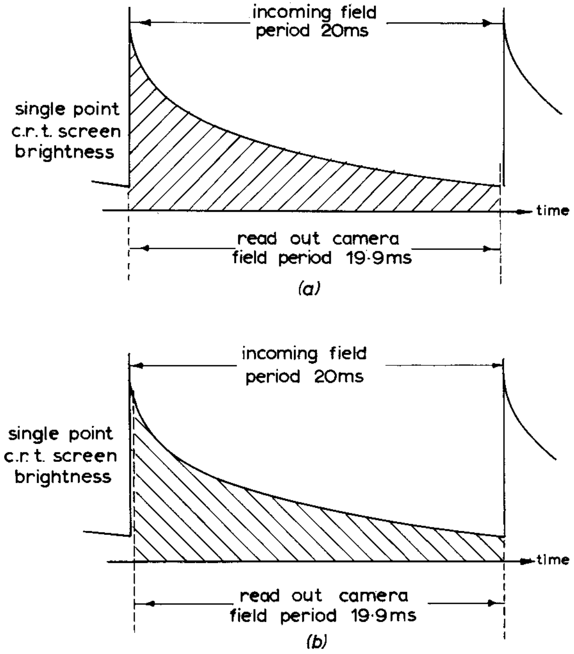

incoming field period
display brightness of a picture element in any given part of field
time
read out camera field period
no exposure during this field

Fig. 2 - The effect of a short-persistence display tube in an asynchronous standards converter

Fig. 3 shows the brightness, as a function of time, of a point on the phosphor screen of a cathode-ray tube having an afterglow representative of that used in present standards converters. If the dissimilarity in input and output field periods is small, (say 0•1 ms, corresponding to a difference-frequency of 0•25 c/s at 50 c/s) it will be seen that the output signal level from the converter


incoming field period 20ms
single point c.r.t. screen brightness
time
read out camera field period 19·9ms
(a)
incoming field period 20ms
single point c.r.t. screen brightness
time
read out camera field period 19·9ms
(b)

$$\frac{\text{maximum camera output}}{\text{minimum camera output}} = \frac{1{\cdot}011}{1}$$

Fig. 3 - Field phasing for maximum and minimum camera outputs. (Camera field frequency-difference of minus 0•25 c/s.)

(a) - phasing for maximum camera output
(b) - phasing for minimum camera output

camera becomes much less dependent on the relative phase of the two field periods since the exposure of a given point during any output scan-period is the integrated light flux at that point, represented in Fig. 3 by the shaded area under the brightness/time curve. The longer the afterglow the more nearly equal must all exposures of the point become.

It will however be noticed that in Fig. 3 the brightness of the point due to any single excitation has not fallen to zero before the next scan occurs. The decay characteristic is not a single pure exponential but is a combination of four exponentials having different time constants, one being of long duration (although of low brightness); thus after one field period of 20 milliseconds the brightness of the point has fallen to only 12·5% of the brightness immediately after the scanning spot has passed. This means that some of the information from a given incoming television field is carried over and displayed with the next incoming field. If there is movement in the scene an object occupies different positions in successive fields, thus it will be displayed as a double image, although of course the brightness of one image will be considerably less than that of the other. The long, low-level 'tail' of the afterglow characteristic (in a practical standards converter display) can, in fact, give rise to a recognizable triple image of moving objects under certain circumstances.

In addition to the direct presentation of multiple images of moving objects, the afterglow of the standards converter display tube can influence their production in another way. Suppose the relative phases of the 'writing' beam in the display tube and the 'reading' beam in the camera tube are as shown in Fig. 4. It will be seen that the total exposure of the camera, represented by the shaded area under the curve, is derived equally from two fields. Thus, if the field repetition rates were identical and this phase relationship were maintained permanently, each output field would contain equal contributions of picture information from two successive fields of the incoming programme.* Any movement in the scene would thus be portrayed in the output by double images of equal, but half-intensity brightness relative to that of any static objects depicted. If the long afterglow 'tail' of the cathode-ray tube had produced any multiple images, as described in 2.2.1. above, all these, too, would appear duplicated at half-intensity but the two series of images would not be separately visible since they would mainly be in register, one upon the other, although displaced by the movement occurring in one field period.

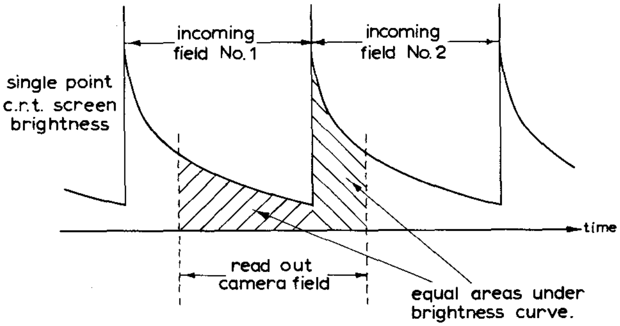

incoming field No.1
incoming field No.2
single point c.r.t. screen brightness
time
read out camera field
equal areas under brightness curve.

Fig. 4 - Field phasing for conversion from equal contributions by two successive fields

The example in Fig. 4 shows equal output contributions from two incoming fields, but it will be noted that, if the two systems are not locked together, there is a slow drift of relative field phase. When the reading of any point in the image by the scanning beam of the camera takes place just before the brightness of that spot is renewed in the display, the majority of the output field is due to information from a single input field and multiple imaging is at a minimum.

* Method suggested by E.R. Rout

As the relative phase changes a second image grows in brightness as the first diminishes until the condition of equality (Fig. 4) occurs and then the process will continue until there is again only one image. A short afterglow reduces the proportion of each beat cycle during which the second image is of significant brightness and it is thus desirable, from the point of view of multiple images, to keep the afterglow period of the display tube as short as is consistent with the substantial elimination of brightness disturbances in the converted picture.

It may be noted here that in television standards conversion where synchronism between the input and output field frequencies is possible, the exact phase depicted in Fig. 4 could always be selected and would bring about an improvement in the vertical resolution of the converted picture. The outgoing field would be made up from two interlaced incoming fields and would thus contain additional information, but the cost would be permanent adoption of the most disadvantageous phase for reduction of multiple images. This, and other aspects of the choice between simple conversion, field by field, or 'conversion in pictures' will be discussed in Section 2.4.

2.2.2. Multiple Images Due to Incomplete Erasure in the Standards Converter Camera

It is an unfortunate feature of all camera tubes employing low-velocity scanning beams that one single scan of the target by the reading beam is insufficient to collect all the information stored during the exposure of the tube. The stored image is therefore not completely erased with each 'reading'. A second scan, without further exposure of the tube to light, may yield as much as 25% or 30% of the signal obtained from the first scan, and tests in the laboratory, using single exposures followed by repeated scanning show that a low-brightness image may in some cases still be obtained after ten or more scans have taken place. When an object moves in the scene it is, therefore, depicted as a series of images, each image, after the leading one, being the contribution from an incompletely erased portion of an earlier field. This effect is generally the worst offender in producing movement errors in the converted picture. It should, however, be remembered that any multiple images due to the afterglow and field-phase effects already described are all multiplied by the effects of incomplete erasure in the camera.

Not all camera tubes used for standards conversion behave alike in this respect and in selecting a camera tube for the purpose, the ability to portray moving objects must be carefully weighed against other advantages or disadvantages of the tube. In Section 4 of this report, entitled 'Objective Measurements of Existing Camera Tubes' the erasure characteristics of the three principal camera tubes, image orthicon, C.P.S. Emitron, and vidicon are dealt with in detail.

In standards converters which use the image orthicon, an additional source of spurious images of moving objects may arise from a lack of target-conductivity.

This effect, which produces a positive after-image resulting from incomplete equalization of the potentials between corresponding points on opposite faces of the target occurs in any image-orthicon tube that has not reached its working temperature (45°C) but, as the working life of the tube lengthens, it shows a greater tendency to occur in normal operation. This is thought to be due to the near exhaustion of the supply of charge carriers in the target glass, resulting in a decrease in conductivity which, of course, also occurs when the target is cold.

This is rather more serious in a standards converting camera than in normal studio operation because movement portrayal is usually already degraded by the other effects mentioned and a tube rejected for this cause in a standards converter might well be acceptable under other circumstances.

2.3. 'Sticking' in the Image Orthicon

The effect known as 'sticking' is peculiar to the image orthicon and takes the form of a negative after-image which persists after the scene has been changed. When it occurs it may vary in severity from permanent retention, following prolonged exposure to a static scene, to a very temporary after-image which quickly fades.

The more severe and permanent 'sticking', or 'burn-in' as it is sometimes called, has an important bearing on the usefulness of the image orthicon as a standards conversion camera tube. It is not the normal practice to allow an image orthicon camera to remain stationary on a scene for any length of time, lest an image be permanently retained. In the standards converter the nature of the displayed image is not under the control of the operators but is determined at the source of the original pictures, and the introduction of still captions, for example, may lead to difficulties. A permanently 'burnt-in' image of a caption or test card superimposed on all subsequent pictures is particularly distracting and liability to this effect is an important factor in considering the choice of camera tube.

2.4. 'Photo-Signal' Effects

In the C.P.S. Emitron camera tube, the signal output voltage is developed across a resistor carrying the signal displacement current. Since this current is the sum of both the target charging and discharging currents, it follows that the camera tube also operates simultaneously as a photo-electric cell and produces an additional 'photo-signal' output which is proportional to the instantaneous total target illumination and is independent of camera-tube scanning. In normal studio use this effect is of no consequence, because the variations in total target illumination are extremely slow and small; even much larger and faster variations would be removed successfully by the camera clamping circuits.

In the case of image-transfer standards conversion, however, the primary image displayed upon the cathode-ray tube may be regarded as an intensity-modulated spot of light and an interfering 'photo-signal' is derived directly from the primary signal in this way. The effect of afterglow in the display-tube on the 'photo-signal' must be considered in conjunction with the action of the clamping circuits in the camera-channel. When an unwanted signal is added to the output of a camera tube, the line-by-line clamping circuit operates upon the combined signal and restores it to black level at the end of each camera line scan. The variations in the wanted output due to the added signal are thereby reduced to the amount by which the added signal may have varied during any line. If a ratio of picture signal to 'photo-signal' of 40 dB (100 : 1) is considered adequate, then it follows that the 'photo-signal' must not vary by more than 1% of the output picture signal during any one camera line scan.

If it is found necessary to employ an afterglow-time which is significantly shorter than that required to give this rate of decay, the effect of the 'photo-signal' may be reduced by another method. This employs an additional photo-electric cell which is fitted to the camera so as to receive light equally from all points on the cathode-ray tube screen. By a suitable electrical subtraction process, the output from this cell is used to cancel the 'photo-signal' output from the camera-tube signal plate.

The normal image-orthicon camera tube has not been found to exhibit any tendency to produce a 'photo-signal'. This is to be expected, particularly in view of the fact that the picture signal is derived from the return beam and that a signal plate is not used.

Experience with the vidicon camera tube also suggested that this tube is not, in practice, subject to 'photo-signal' effects.

2.5. Vertical Resolution

2.5.1. General

All standards converters in current use employ a field-by-field system of conversion, i.e. the image displayed to the conversion camera is substantially limited to information from one field and thereby contains only half the total number of lines actively displayed in an interlaced picture. An essential feature of any system of standards conversion (including film telerecordings to be rescanned) is that the original line structure is removed at some stage in the process, otherwise line-beating effects, producing moiré patterns, will be apparent in the converted picture. A detailed analysis of the effects of scanning in lines, and the results of broadening the scanning lines by various means is given in a Research Department Report.[5] In the image-transfer standards converter the only means so far employed for eliminating line beating has been by the use of sinusoidal spot-wobble in conjunction with the fact that the 'writing' beam has a finite cross-section. It is shown in the report referred to above that, although sinusoidal spot-wobble suppresses the fundamental line-frequency component of the 'vertical spectrum'* of the displayed image and also reduces the harmonics of this unwanted component, there is a loss of vertical resolution. It would, therefore, be very desirable to reduce the amount of line-broadening necessary in the conversion display and also to consider means of obtaining an effective line profile which is a better approximation to the ideal 'sampling function' form of cross-section, (sin x)/x. These aspects are dealt with in another paper[6] but the principal considerations may be stated briefly here.

2.5.2. 'Conversion in Pictures'

A reduction in the amount of spot-wobble required can be achieved by the simultaneous display of both the odd and even fields of the incoming pictures. The number of lines in the image exposed to the conversion camera is thus doubled and (neglecting the writing beam) the required spot-wobble amplitude is halved. Means of achieving this have hitherto been so difficult instrumentally that the method has not been employed except in an experimental arrangement of the simple artifice mentioned in sub-section 2.2.1., where it was stated that an exact phase relationship between the reading and writing beams could, in an isochronous system of standards conversion, bring about an improvement in the vertical resolution of the converted picture. Where the input and output signals are either both locked to the same mains supply or have the same stable scanning frequencies, the line-storage type standards converter would, however, be preferred and the simple method of achieving 'conversion in pictures' is therefore only likely to be useful in appraising the value of more practical means of achieving the same object.

---

* The Fourier transform of the brightness of the image expressed as a function of distance measured vertically downwards.

A simultaneous presentation of the odd and even fields of the incoming television signal requires the ability to delay the signal by one field period. Given this facility, the presentation to the converter camera might, for example, be by means of two cathode-ray tubes whose images are combined by a semi-reflecting mirror;[7] one tube would display the incoming signals directly, while the other would display the same signals after they had been delayed by approximately one field period. The spot-wobble amplitude would be adjusted to suit the combined optical image, rather than each individual raster, and vertical resolution would be improved. An obvious difficulty posed by this system is that of maintaining linearity and registration so that no part of the converted picture exhibits line-beating effects.

An alternative approach would be to use a form of 'synchronous spot wobble'[8,9] applied to a single cathode-ray tube display. In such a case, all the positive-going half cycles of the spot-wobble deflections would be used to write information from one field while all the negative-going half cycles provided contributions from the succeeding field. Again the second signal would be obtained by introducing a delay of about one field period.

A delay line capable of 20 milliseconds delay, with a bandwidth of not less than 3 Mc/s, is now becoming a practical proposition and may well lead to an important improvement in image-transfer standards conversion. Fortunately, 'conversion in pictures' is a modification which could be applied to an existing image-transfer standards converter and the immediate choice or construction of new apparatus need not be unduly influenced by the availability of field-period delay apparatus.

It should be mentioned, however, that 'conversion in pictures' will not be without disadvantage and the arguments advanced in its favour apply only to static objects in the scene. Where there is a moving object its images in two successive fields (combined either optically or by synchronous spot wobble), will not be superimposed since they differ by one field period in time of origin. Each will therefore be portrayed by the line structure of only a single field bearing only half the necessary amplitude of spot wobble. It follows that moiré patterns will occur and add to the degradation due to a double image of half-brightness (see Section 2.2.1.).

2.5.3. Vertical Aperture Correction

Further improvement in vertical resolution could be obtained by other modifications of the effective profile of the scanning line. The finite dimensions of the display tube scanning spot may perhaps be further reduced by the use of new techniques in electromagnetic cathode-ray tube focusing and the correction of the beam profile for astigmatism (see Section 5.5.). It has been demonstrated that an important contribution can be obtained from the vertical aperture corrector proposed by Gibson and Schroeder,[10] which is able to give the effective line profile an approximation to the ideal '(sin x)/x' form. This it achieves by suitably combining with the input video signal two low-level signal contributions (of opposite polarity to that of the input) obtained from the two lines in the same field immediately above and below that being written; two separate line-period delay devices are used to bring the three signals into synchronism so that the subtraction may be performed. With this corrector the vertical resolution is improved without reducing the rejection of the fundamental component of the 'vertical spectrum' or introducing extraneous components. If a field-period delay device were available, the performance of the vertical aperture corrector could be still further improved, since the components subtracted from the main signal could be taken from spatially adjacent lines of a picture rather than from the nearest lines in the same field.

A vertical aperture corrector incorporating a field-period delay could, in addition to improving vertical aperture correction, provide compensations for a secondary image due to incomplete erasure in a camera tube. Hughes[11] has used a magnetostrictive delay line in this way.

2.6. Noise

The addition of noise by the standards converter must obviously be reduced to a minimum. The visibility of added noise will, however, be somewhat dependent on the mode of operation of the converter display and this may call for a compromise with other parameters. It is necessary that the overall gamma of the standards converter be unity, so that a conventional cathode-ray tube (of gamma = 2·5) used with any of the camera tubes (of gamma = 0·8 to 1·0) so far employed in standards converters will make some non-linear amplification ('gamma correction') essential. It is possible to provide this in the drive to the cathode-ray tube or in the output of the converter camera; it may, however, be found desirable to divide the function between the two positions.

It has been found that the visibility of random noise over the grey scale of a television picture differs somewhat from that of fixed patterns. This investigation is described in a Research Department Report[12] and reference to Fig. 3 of that report will show that below 30% peak picture-signal level, there is a substantial increase in the level of random noise required to produce a given visibility.

Each of the cameras considered for standards conversion (C.P.S. Emitron, image orthicon and Vidicon) produces noise which, in the absence of any form of gamma correction, is substantially independent of the instantaneous signal level and therefore this distribution in the grey scale, as it stands, is not ideal for minimum visibility. It must be remembered, however, that the noise generated in the standards converter is added to that of the incoming pictures, and the distribution of the latter noise throughout the grey scale is not always the same. In studio productions, using C.P.S. Emitrons or image orthicons for example, it is usually found necessary to use lighting effects to reduce the amount of non-linear amplification required in the camera channels, because full correction of the contrast law of the camera by non-linear amplification produces more noise in the dark tones than can be tolerated. On the other hand, if the incoming pictures have been obtained from a flying-spot scanner, then the noise after contrast-law correction will have a substantially constant magnitude at all picture-signal levels.

If the standards converter were used to duplicate a complete service, roughly equal portions of the input would probably originate from film scanners and studios (the latter mainly via video tape recorders) and it is therefore not immediately obvious which of the possible distributions of noise added by the converter would have the least harmful effect.

The optimum division of the gamma-correction process between the circuits located before and after the optical image-transfer is also influenced by considerations of the visibility of incompletely erased images of moving objects, phosphor granularity and optical flare. The last two factors are mentioned briefly in the following sub-section.

2.7. Optical Distortions

2.7.1. 'Background'

Static patterns of grain and other blemishes superimposed on the converted picture are common and easily recognized faults in pictures obtained by image-transfer standards conversion: the unwanted additions arise from the grain-structure of the cathode-ray tube phosphor and from minor blemishes in the camera tube. Recent advances in cathode-ray tube techniques have brought about a substantial reduction in phosphor granularity and there should be a significant improvement when the new tubes are placed in service. Detailed information is given in Section 5.3.

Blemishes are responsible for the majority of rejections of camera tubes during manufacture and the acceptable degree of imperfection is most carefully specified. Camera tubes offered for normal service are generally likely to be satisfactory but the visibility of their 'background' is nevertheless somewhat conditioned by the operating conditions of the converter.

Phosphor grain from the cathode-ray tube and blemishes in the camera are manifest as modulations of the wanted picture signal, i.e. the disturbance is proportional to the mean brightness at which it occurs. Hence it follows that the fraction $\Delta B/B$, where B is the brightness, is a constant throughout the grey scale. At brightness levels greater than 10% peak, this corresponds to the requirement for minimum visibility of fixed coherent patterns (See Fig. 4 of Research Department Report T-092) and, therefore, it is desirable that the contrast law of the picture displayed on the viewer's receiver should be equal to that of the picture on the converter cathode-ray tube. To achieve this the contrast-law of the converter camera would need to be corrected to a gamma of 0·4 or 0·5 over most of the brightness range and this implies that virtually the whole of the gamma correction of the standards converter should take place after the camera, and none prior to the display tube. This is not compatible with what is probably the best arrangement from other points of view, but the recent significant improvements in cathode-ray tubes make this aspect rather less important than it has been in the past.

2.7.2. Cathode-ray Tube Flare

The effects of flare in a cathode-ray tube are now very well known.[13] Spurious information added to the standards-converted picture from this cause will, like noise and background, be affected by the position of the contrast-law correction circuits in the converter. The most obvious distortion due to flare in the tube lies in the dark tones of the picture and it is therefore advisable, from this point of view, to avoid gamma correction after the addition of flare.

3. AN APPRAISAL OF THE MOVEMENT PORTRAYAL PROVIDED BY EXISTING APPARATUS

3.1. Method of Measurement

Three different types of image transfer standards converter are at present used by the BBC and a fourth is on order. These are as follows:

Eurovision Converter, Tolsford Hill, Dover[14]

Type P.812 4½-inch image orthicon in Marconi Mk III camera, Cintel 9-inch display tube.

60 Fields/sec to 50 Fields/sec, Television Centre[15]

CPS Emitron camera, Ferranti 9-inch display tube.

Marconi Converter, Television Centre[16]

Type P.822 4½-inch image orthicon in Marconi Mk IV camera, Ferranti 6-inch display tube.

Fernseh Converter (on order)[17]

1-inch Vidicon tube in Fernseh camera, Fernseh 4-inch display tube.

The critical appraisal of the equipments in operation gives some opportunity to compare the performance obtained from different approaches to the problem. A series of tests to determine the production of multiple images of moving objects was carried out and the results may usefully be compared with the characteristics of the display and camera tubes measured under laboratory conditions and quoted in Sections 4 and 5.

A special unit was constructed for the purpose of the investigation. This unit generated a line-frequency pulse, approximately 2 μs wide, corresponding to a narrow white vertical stripe on a black background and this was caused first to appear on the left-hand side of the picture and then to move, field-by-field, across the picture to the right hand side. The lateral movement between successive fields was adjusted to be about one and a half times the width of the pulse itself. The signal thus synthesized a fast-moving object, the whole sequence appearing as a smooth succession of discrete images that traversed the width of the picture in less than one second.

To test a standards converter the signal was applied to the display unit in place of the normal picture signal and the converted output was displayed for photographing on both a line-selecting waveform monitor and a picture monitor. Photographs were taken as the pulse neared the right-hand edge of the picture, the camera shutters being open for slightly less than one field period.

Throughout these tests, the 405-line standard was used for both input and output and the two field frequencies were identical. In practice, when a difference in field frequency exists, the portrayal of motion by the standards converter is found to vary in a cyclic manner, as described in Section 2.2.2. During the investigation, this effect was synthesized by selection and adjustment of field phasing. In Figs. 5 to 9 the condition illustrated is in each case that which gives the maximum contribution from a single incoming field and hence the minimum multiple imaging.

3.2. Results

The photographs taken from the picture monitor displaying the converted output do not give a completely objective guide to the performance of the converter alone since they include the effects of the afterglow from the picture monitor and the non-linear characteristic of the photographic process.

Tolsford Hill Eurovision Converters (P.812 image orthicon)

Fig. 5 shows the results obtained when this equipment was first tested. It was immediately apparent that the portrayal of motion was very poor owing to the large number of after-images. This was found to be due, in part, to abnormal 'sticking' in the target of the image orthicon camera tube, which had passed the end of its useful life. A new P.812 4½-inch image orthicon camera tube was fitted, and the results then obtained are shown in Fig. 6.

A greater number of low-level after-images is discernible in the photograph of each picture display than in the corresponding waveform photograph; this effect was also visible at the time of the experiments, when more after-images could be seen directly on the picture-monitor than could be found in the waveform. It seems that whilst the waveform monitor gives an accurate measure of the higher amplitude after-images, the picture monitor gives a more reliable indication of the total number of images that are discernible.

Television Centre. The C.P.S. Emitron Converter

Fig. 7 illustrates the result of the test applied to the C.P.S. Emitron converter at Television Centre, operating under 50 fields to 50 fields per second conversion conditions. Fig. 8 gives the result of replacing the normal display tube phosphor with one having a much shorter afterglow time. When Fig. 8 is compared with Fig. 7, it will be seen (particularly from the waveforms) that some improvement in movement portrayal is gained.

Television Centre. The Marconi Standards Converter

This equipment showed results which were very similar to those obtained from the Tolsford Hill standards converter when a type P.822, 4½-inch image orthicon camera tube was substituted for the normal type P.812 tube. Details are given in Fig. 9.

Portrayal of motion of synthesized moving object

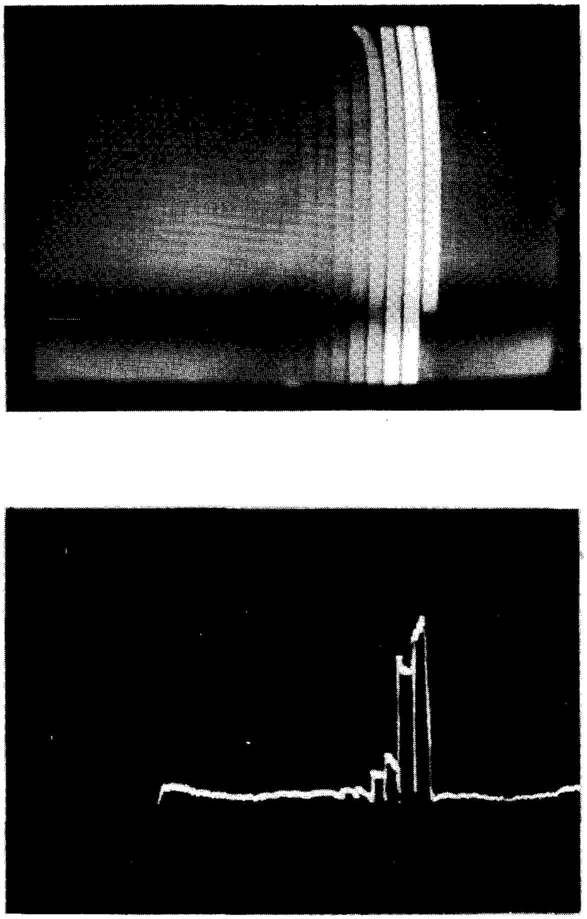


Fig. 5 - Tolsford Hill converter using worn-out P.812 image orthicon

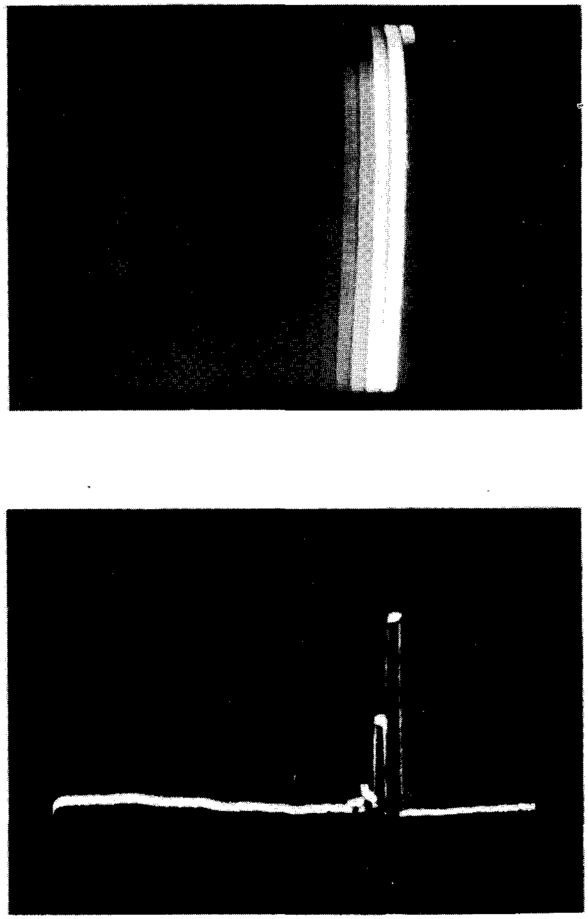


Fig. 6 - Tolsford Hill converter using new P.812 image orthicon

3.3. Comparison of Results

The photographs of the waveforms obtained in the tests just described were analysed by measurement of the pulse magnitudes with a travelling microscope. A selection of the results is shown in Fig. 10.

The Marconi (type P.822, 4½-inch image orthicon) and C.P.S. Emitron equipments are seen to produce after-images that are lower in amplitude and fewer in number than those employing the P.812 image orthicon.

The motion-portrayal ability of the Fernseh equipment has not been measured, but an impression of the results which can be expected is obtainable from the separate measurements which have been made of the erasure characteristic of the Vidicon camera tube. These are discussed in Section 4 and are compared with those of the 4½-inch image orthicons and the C.P.S. Emitron.

Portrayal of motion of synthesized moving object

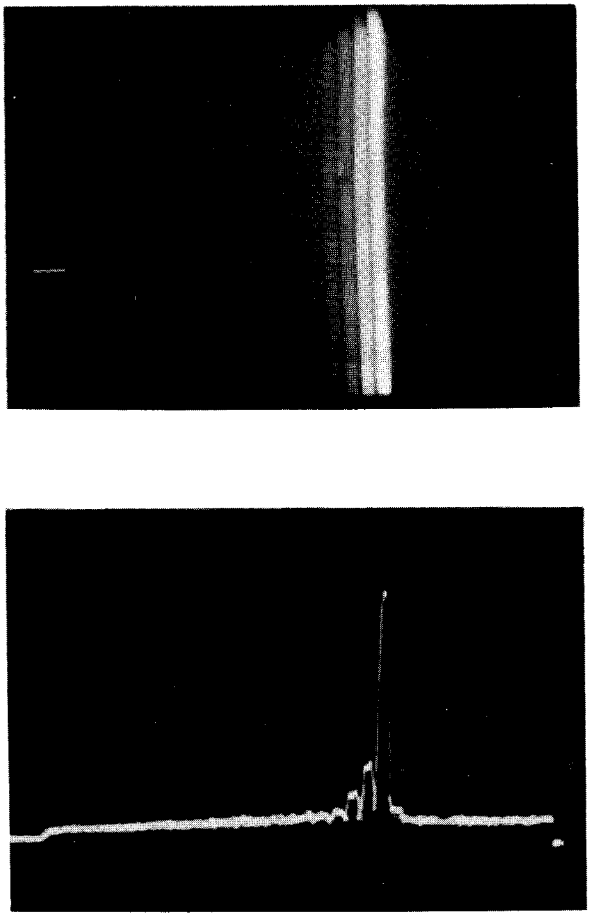


Fig. 7 - C.P.S. Emitron converter with normal display tube

4. OBJECTIVE MEASUREMENTS OF CAMERA TUBES

4.1. General

Specimen tubes of the types listed below have been measured in those respects which are of direct concern for standards conversion. Results are given in the form of graphs from which the performance of the various types may be compared.

(a) *4½-Image Orthicon, Type P.812.* This is a 'close-spaced' tube having only 0·0005 inch (0·013 mm) separation between the target and its associated target-mesh. It has a high storage capacity with a consequently high signal-to-noise ratio but rather low sensitivity. Erasure of stored images is poor owing to the long effective discharge time-constant.

(b) *4½-inch Image Orthicon, Type P.822.* This type of tube is used in the majority of BBC studios, has a 'medium' spacing between the target and the target-mesh (approximately 0·0015 inch (0·038 mm)) and hence it has less storage capacity than the P.812 and a less good signal-to-noise ratio, but a better erasure of stored images and more sensitivity.

(c) *C.P.S. Emitron.* This is a conventional orthicon tube without either image section or electron multiplier. It has limited sensitivity and its signal-to-noise ratio is controlled by the properties of the head amplifier rather than predetermined within the tube. The tube shows fairly good erasure characteristics but is subject to 'photo-signal' difficulties.

(d) *Vidicon.* This is a one-inch photoconductive tube that has a relatively low sensitivity and poor erasure characteristics, but excellent signal-to-noise ratio, stability and ease of operation.

Portrayal of motion of synthesized moving object

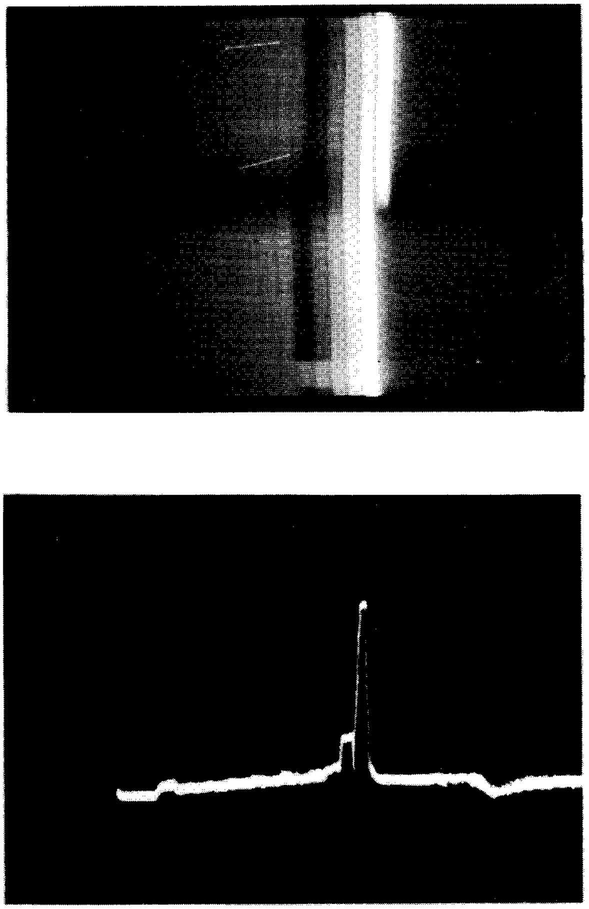


Fig. 8 - C.P.S. Emitron converter with short persistence display tube

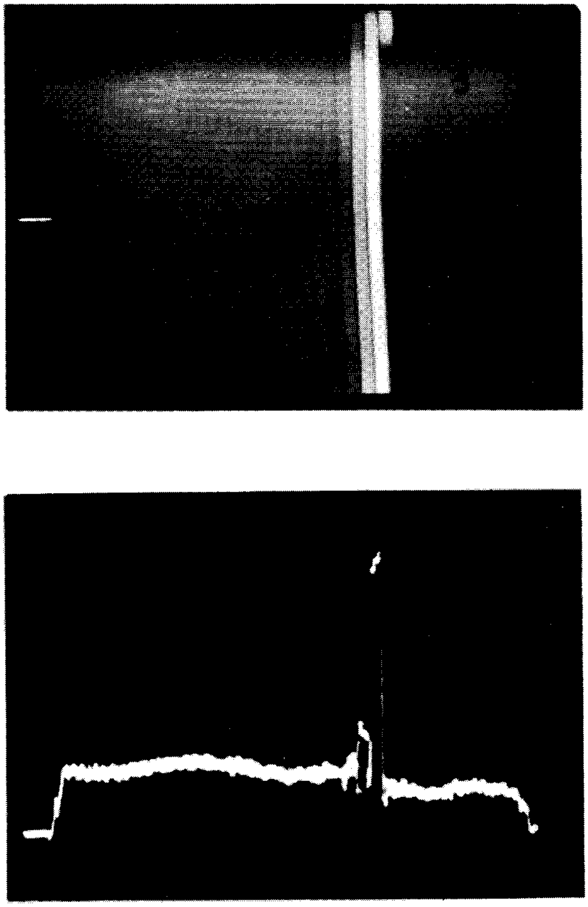


Fig. 9 - Marconi converter with P.822 image orthicon

(e) *4½-inch Image Orthicon (Experimental 'Stick-Resistant' Target).* This tube was produced by English Electric Valve Co. Ltd. specially for this investigation, and is part of a series of experiments with new target materials.[18,19] It is a close-spaced tube having the dimensions of a P.812 tube, and a performance that is similar, except in respect of sticking. Its resistance to 'sticking' is such that former objections to the use of the image orthicon for standards conversion, on this account, are no longer valid.

4.2. Comparison of Performance

4.2.1. Sensitivity

The light transfer characteristics of the tubes are given in Fig. 11.

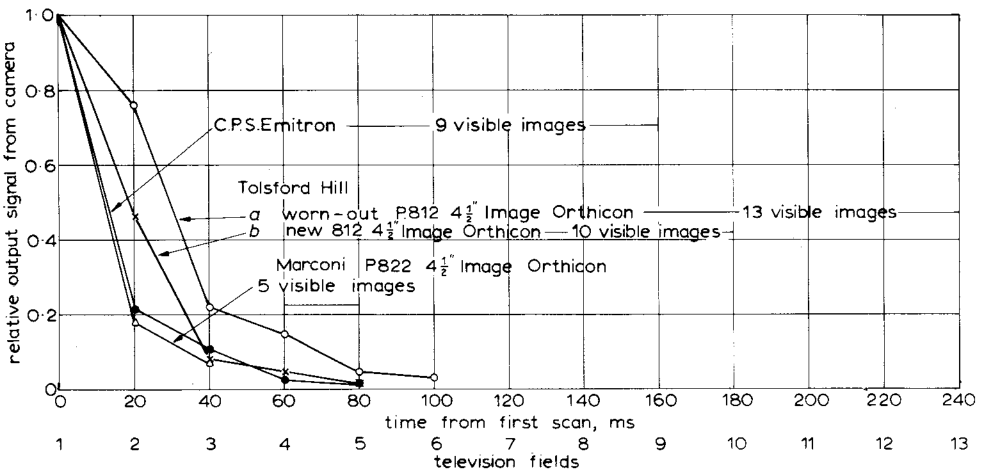


Fig. 10 - Motion portrayal of operational standards converters - magnitude of after-images produced by synthesized moving object

In the image orthicon the normal potential of the target-mesh is +2·5 V to +3 V with respect to its cut-off value, and in ordinary use potentials in excess of this are not advised since high currents in the target due to highlights may damage the target material and reduce the life of the tube. Where, however, it is possible to place a guaranteed specific limit on the target current by limiting either the light input or the beam current used, the potential of the target-mesh may be increased so that

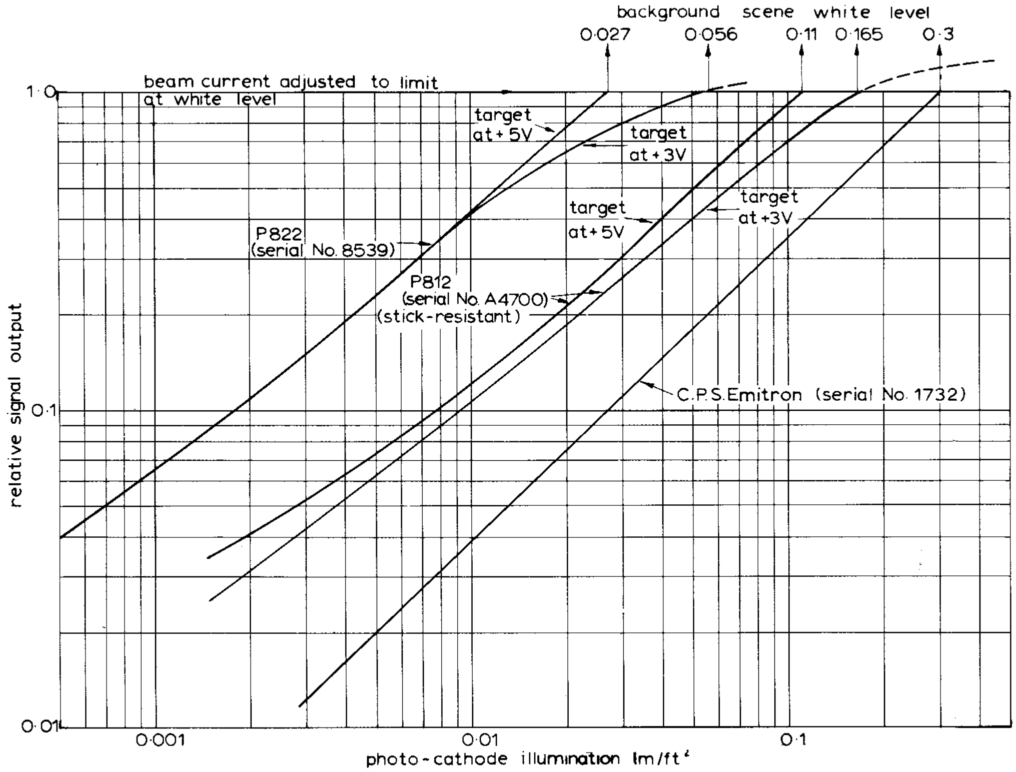


Fig. 11 - Light-transfer characteristics of camera tubes

the 'knee' of the characteristic occurs outside the permitted working range of the tube. The light transfer characteristic now becomes very much more linear. This artifice is used in colour cameras but is equally applicable to standards conversion; the beam modulation efficiency is increased and the signal-to-noise ratio may be improved by 2 dB in some cases.

When the Vidicon is operated as a standards converter camera, it is necessary to use more than 20 lumens per square foot (215 lux) incident upon the photo-cathode. The Vidicon has a contrast law which is less linear than those of the C.P.S. Emitron and image orthicon and which varies in gamma with incident light. Under studio conditions, where the incident light used at the photo-cathode is of the order of 6 to 10 lumens per square foot (64 to 107 lux) the point gamma varies from 0·65 to 0·8. Under telecine conditions, however, where photo-cathode illumination may be between 100 and 200 lumens per square foot (1076 to 2152 lux) the point gamma falls to 0·4. The contrast-law correction required is therefore somewhat different from that required by the other cameras, and the Vidicon converter is less flexible in ability to arrange for the optimum distribution of noise throughout the grey scale, reduction in visibility of flare, grain, and low-level multiple images due to incomplete erasure.

4.2.2. Horizontal Resolution

Typical horizontal-resolution curves are shown in Fig. 12. In a number of samples measured, the P.812 and P.822 image orthicons gave very similar results,

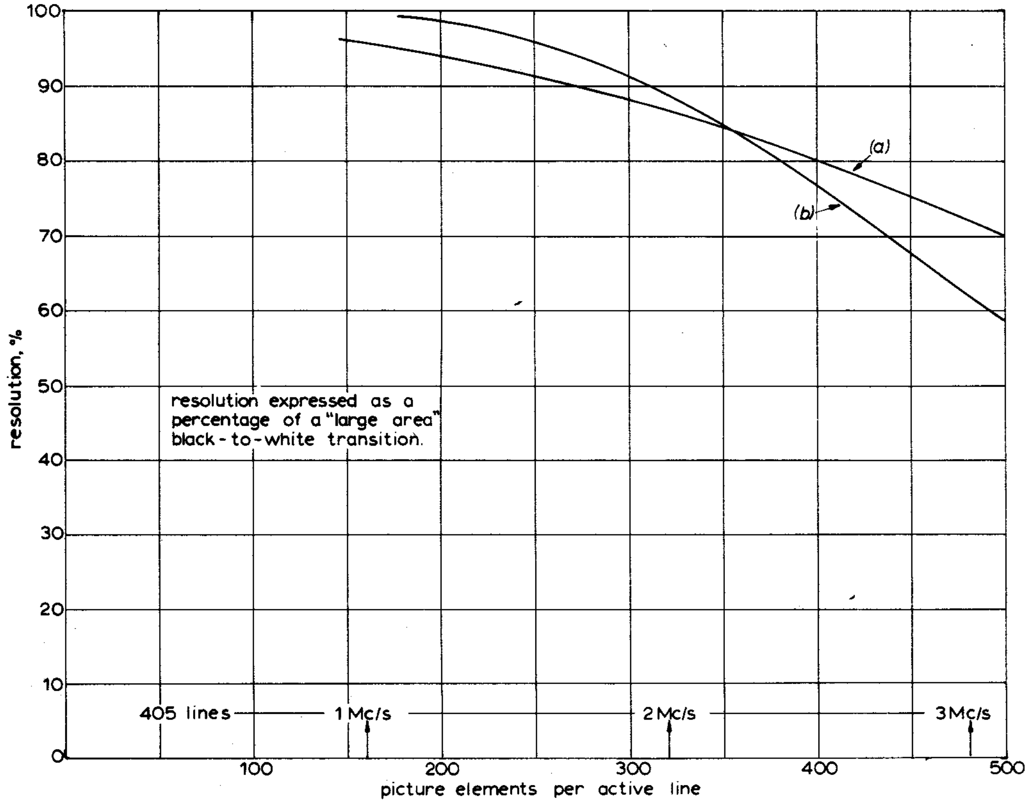


Fig. 12 - Horizontal resolution of camera tubes

(a) - C.P.S. Emitron (b) - P.812 and P.822

as also did the experimental 'stick-resistant' P.812 tube. This was particularly gratifying since it had been thought that the resistance to sticking might be acquired only at the cost of resolution. A typical result for all 4½-inch image orthicons is therefore given. The C.P.S. Emitron resolution characteristic shown indicates a slightly better high-frequency response than the image orthicons but the difference between them is not very significant.

Until recently the Vidicon would have shown up quite badly in this context. E.M.I. have, however, demonstrated experimental Vidicons[20] in which the mesh and wall-anode are no longer internally connected so that a potential difference may be created between them. The effect upon resolution is very marked and results comparable with the 4½-inch image orthicon have been claimed; a figure of not less than 50% modulation at 3 Mc/s on the 405-line scanning standard, has been measured.

4.2.3. Signal-to-noise ratio

Signal-to-noise ratios shown in Table 1 below were determined by means of the Research Department noisemeter[21] and represent the peak signal-to-r.m.s. noise ratio at the output from the tube and its associated head amplifier.

TABLE 1

Peak signal-to-r.m.s. noise

CAMERA TUBE TYPE	SIGNAL/NOISE DECIBELS	REMARKS
P.822 Medium-Spaced image orthicon	39	Target at +3·0 V (no improvement at +5·0 V)
P.812 Close-Spaced image orthicon (stick-resistant)	41 43	Target at +3·0 V Target at +5·0 V
C.P.S. Emitron	38·4	Triangular spectrum noise: add say 5 dB for equal visibility with image orthicons (see Section 7.1.2.)
Vidicon	44	Ditto

The performance of P.812 (stick-resistant target) and the normal P.812 image orthicon are similar in respect of noise.

4.2.4. Erasure of redundant information

Measurement of erasure characteristic was carried out in the laboratory by means of a small-area light source to which the camera was exposed through an aperture in a rotating disc driven by a synchronous motor. A small area of the photo-cathode was illuminated for 18 ms, once every tenth field scan; the camera received no light at all during the next ten scans so that the decreasing output with successive 'readings' of the target could be measured and plotted.

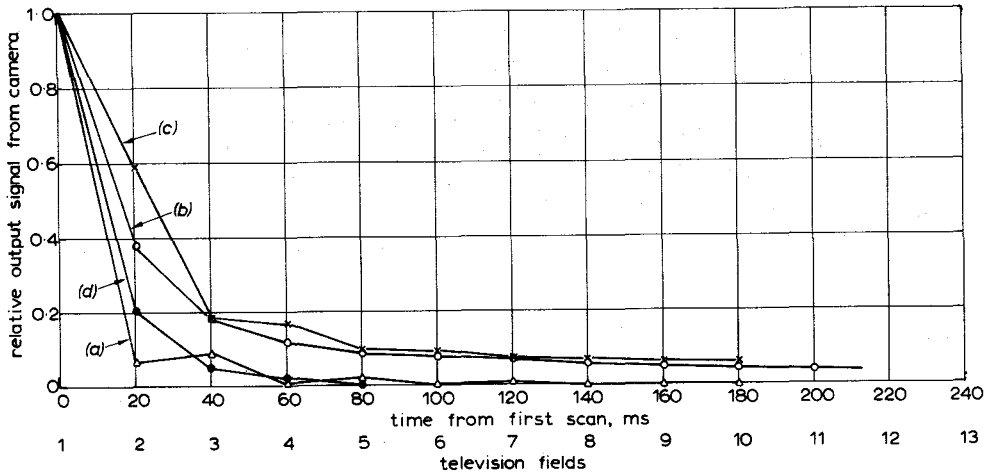


Fig. 13 - Camera tube erasure characteristics (405 lines)

(a) - C.P.S. Emitron
(b) - E.M.I. Vidicon type 10667 (S) (20 lm/sq. ft. incident at target)
(c) - 4½-inch image orthicon type P.812 (stick-resistant target)
(d) - 4½-inch image orthicon type P.822

The results are shown in Fig. 13* and may be compared with those shown in Fig. 10, which were obtained from the operational converters by means of the electronically generated moving test object.

The influence of the display tube persistence can be seen in Fig. 10 as an increased output during the second scan following extinction of the optical image, but there can be no doubt that the erasure characteristic of the camera tube is the dominant factor in the production of multiple-images of moving objects.

5. OBJECTIVE MEASUREMENTS OF EXISTING DISPLAY TUBES

5.1. Measurement Methods

The cathode-ray tubes used in each of the existing image-transfer standards converters have been examined in the laboratory and the results of measurements made are given below. Although the brightness, and afterglow of the phosphor may be measured in absolute terms, granularity and uniformity are difficult to specify in this manner and the most satisfactory technique so far used is to make comparisons by means of photography. The tube is scanned in the usual manner and maximum beam-current is used, but the beam is defocused to the maximum extent; the whole phosphor screen is uniformly energized during the course of a field scan. A unit magnification photograph is then taken using fine-grain emulsion plates with a sufficiently long exposure to remove any unevenness due to the inclusion of fractions of a complete scan. The unity magnification negative is then enlarged on to bromide paper; all photographic processes are carefully controlled to give constant conditions and it is found that comparison of the results obtained in this manner will give a reasonably reliable indication of the relative merits of each tube.

---

* The results for the Vidicon were obtained by Mr. B.S. Pover, Tel. O. and M. (L.S.) using a similar measuring technique together with operating conditions equivalent to use in a standards converter, except that the tube exposure time was considerably longer.

Expression of the afterglow characteristic of a phosphor requires careful consideration. It has been the practice to quote the time taken for the brightness to fall to $1/e$ ($\simeq$ 37%) of its initial value, since this is sufficient to describe the whole of the characteristic if the decay follows a single exponential law. This, however, is not true of the Willemite phosphors which have afterglows of the right order for standards conversion but, as already stated, are the sum of several (usually four) components decaying exponentially. One component is a short, high intensity, initial 'flash', lasting only one or two microseconds and contributing negligibly to the exposure of the camera while another is the long low-level tail which sometimes gives rise to noticeable multiple images in the display. A graph of the conventional brightness/time characteristic is difficult to interpret when considering its effect upon devices which integrate the light received from the displayed image, e.g. standards-converter cameras or film telerecorders, and it is more appropriate to plot the cumulative exposure as a function of time. This, of course, is the integral of the brightness/time characteristic; in cases where the decay characteristic is a single exponential, the two curves are very simply related but in the more usual case of a combination of several exponentials the cumulative-exposure graph weights the contribution of each in accordance with its time constant.

The measurement results in this report are given in terms of both methods: in order to give some numerical indication of the afterglow duration (notwithstanding the reservation stated on the usefulness of this method), the figure given is the time taken for the brightness to decay to 10% of that level which existed immediately following the decay of the initial 'flash'.

The cathode-ray tubes employed in existing standards converters are:

9 inch (23 cm) Ferranti Willemite Phosphor 9/24/DM (C.P.S. Emitron converter)

9 inch (23 cm) Cintel Willemite Phosphor C106/J2F 3/8 (Tolsford converter)

6 inch (15 cm) Ferranti Willemite Phosphor 6/22/DM (Marconi converter)

4 inch (10 cm) Fernseh Willemite Phosphor BMP/10/9 (Fernseh converter)

The 6-inch (15 cm) Ferranti tube contains the same phosphor as the 9-inch (23 cm) version and therefore only the latter was examined in detail.

5.2. Afterglow

Measured afterglow characteristics of the tubes are shown in Fig. 14, in which it will be seen that the afterglow of the Cintel phosphor is slightly the shorter, 18·8 ms to the 10% point against 23·0 ms in the Ferranti tube.

More than 9% of the initial brightness remains after 20 ms, at which time the adjacent interlaced lines of the next field are being 'written', and one or two per cent is still visible when the third field scan occurs.

Afterglow of this order is necessary in the present C.P.S. Emitron converter because of the large field-frequency difference and the 'photo-signal' effects encountered. In image-orthicon converters dealing only with a small field-frequency

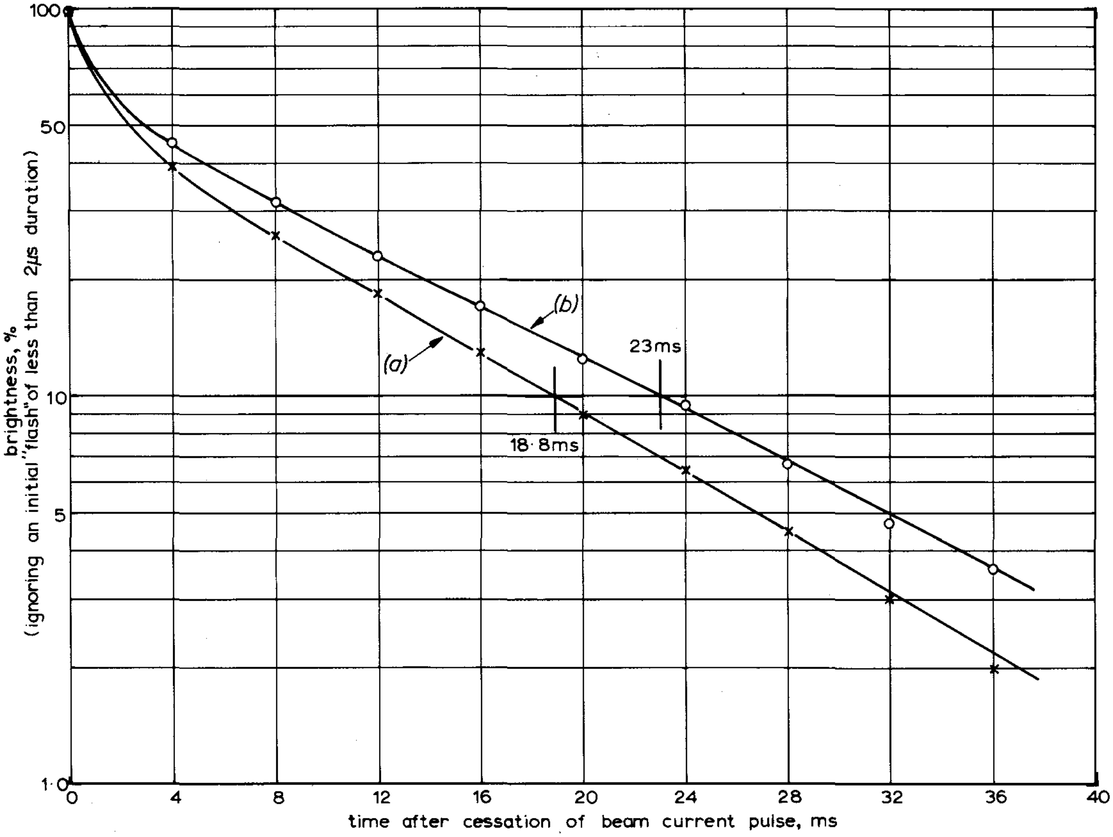


Fig. 14 - Short-pulse afterglow characteristics of operation display tubes

(a) - Cintel C106/J2F3/8 (b) - Ferranti 9/24/DM

difference and having no liability to photo-signal, a shorter afterglow could be used in order to reduce multiple-images. The cumulative exposures given by these tubes are shown in Fig. 15.

Some shorter afterglows are illustrated in Fig. 16. These were obtained from an experimental 9-inch (23 cm) Mullard tube, an experimental Ferranti tube and the Fernseh tube. The cumulative exposures are shown in Fig. 17.

5.3. Phosphor Grain

None of the tubes at present in service is entirely satisfactory from the point of view of phosphor grain. Photographic X5 enlargements of the Cintel C106/J2F 3/8 and the Ferranti 9/24/DM screens are given in Fig. 18: the Cintel tube is clearly much superior in this respect. As a result of discussions with Ferranti Ltd., a new tube (9B/24/D2M) has been developed having the afterglow characteristic shown in Fig. 16, curve (b), but a greatly improved grain structure (Fig. 19(a)) so that it is now superior to the Cintel tube whose phosphor, although of fine grain, tends to be rather 'blotchy' and unevenly distributed. It is, however, likely that further improvements will be forthcoming from both manufacturers and these will

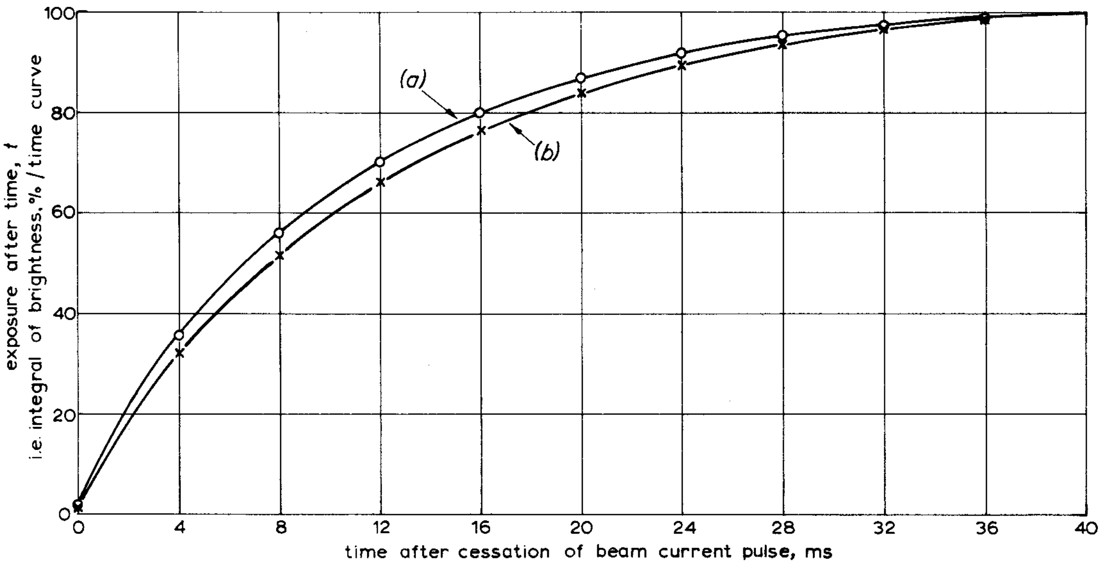


Fig. 15 - Cumulative exposure by operational display tubes

(a) - Cintel C106/J2F (b) - Ferranti 9/24/DM

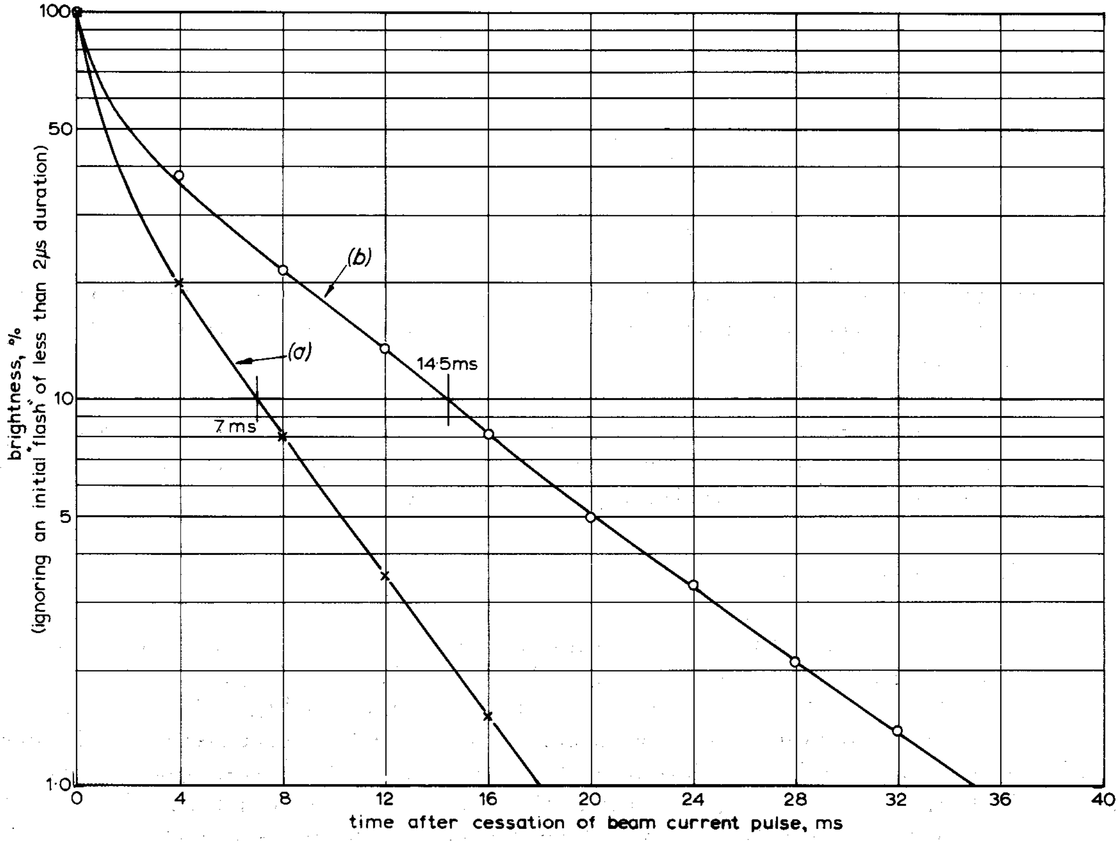


Fig. 16 - Short-pulse afterglow charactertistics of display tubes not yet in service

(a) - Mullard 22/CDD 9/18 (b) - Ferranti 9B/24/D2M and Fernseh BMP 10/9

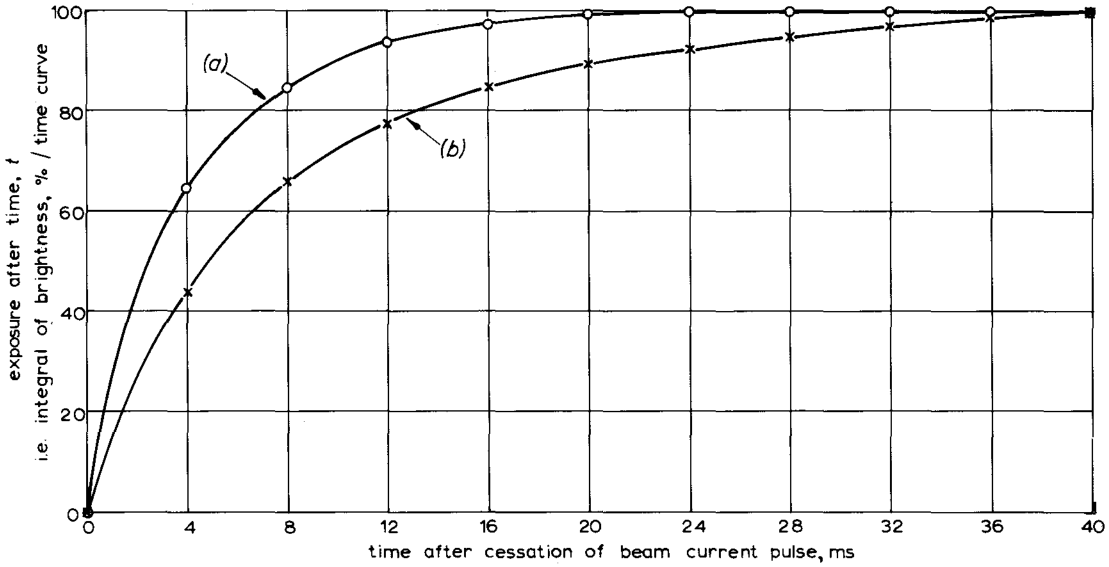


Fig. 17 - Cumulative exposure by display tubes not yet in service

(a) - Mullard 22/CDD9/18 (b) - Ferranti 9B/24/D2M and Fernseh BMP 10/9

undoubtedly reflect on the performance of the standards converters in which they are employed; the C.P.S. Emitron converters at Television Centre are to be fitted with the new Ferranti tubes as soon as these are received.

Regrettably the grain of the shorter-persistence experimental Mullard tube 22/CDD 9/18 is so poor that it cannot be considered for standards conversion. The Fernseh phosphor (Fig. 19(b)) is very much better, although not as good as either the Cintel or the new Ferranti phosphor, and, of course, it suffers from the disadvantage of being used in a tube only 4-inch (10 cm) in diameter so that it is also coarser in terms of picture element dimensions.

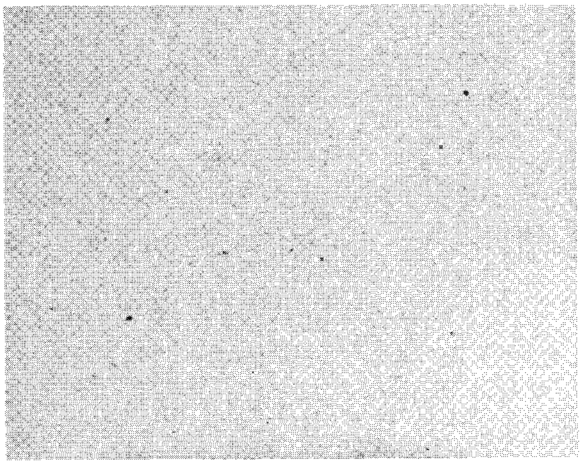
5.4. Screen Brightness

Graphs of tube brightness against beam current at the stated anode potentials are shown in Fig. 20. The Fernseh tube, developed specially to provide a suitable image for standards conversion by means of the Vidicon is capable of outstanding brightness, but the Cintel and Ferranti tubes have performances adequate for the converter cameras with which they are used.

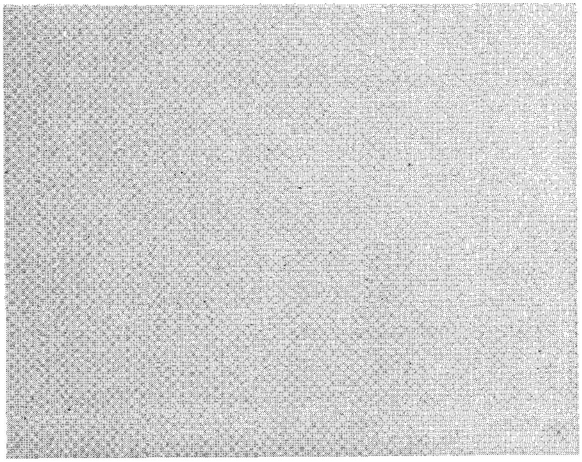
5.5. Resolution

At the present time, the equipment available for the accurate measurement of cathode-ray tube resolution is incomplete and objective measurements have not been possible. High-grade tubes intended for broadcasting purposes all tend to be of comparable resolution and although the Fernseh tube may sacrifice some spot size to achieve very high brightness, the performance at more normal light output levels is certainly very good indeed.

The resolution obtained from any high-quality tube is, moreover, very dependent on the focusing and scanning components with which it is used and it is not inappropriate to mention here a new focus coil assembly which has been developed by Ferranti in association with R.R.E., Malvern. In this device, very precise mechanical mounting is unnecessary and accurate alignments, with astigmatism control, are obtained by potentiometer adjustment, a facility which should bring about a general improvement in the resolution obtained under operational conditions.



(a) Ferranti 9/24/DM



(b) Cintel C106J2F 3/8

Fig. 18 - Phosphor grain photographs x 5 magnification operational display tubes

5.6. 'Sticking' in Display-Tube Phosphors

Many phosphors exhibit semi-permanent retention of a negative image after prolonged display of a fixed pattern. This is similar to the 'sticking' or 'burn-in' phenomenon in the image orthicons and, unfortunately, seems to be particularly marked in the Willemite phosphors which are used for standards conversion.

6. SUBJECTIVE TESTS OF STANDARDS CONVERSION ARRANGEMENTS

6.1. Method of Testing

An experimental arrangement was set up in the laboratory in which the new, fine-grain Ferranti display tube was used in conjunction with each of the image orthicons and also the C.P.S. Emitron. A laboratory test has the advantage that precisely the same programme material (magnetically recorded) can easily be made available for each appraisal, which may, in turn, be made conveniently by a fairly large panel of experienced observers. In particular, subjective judgements of movement portrayal require precisely the same input pictures if a proper appraisal is to be carried out, and the observers may require several repetitions of a sequence before finally awarding a score.

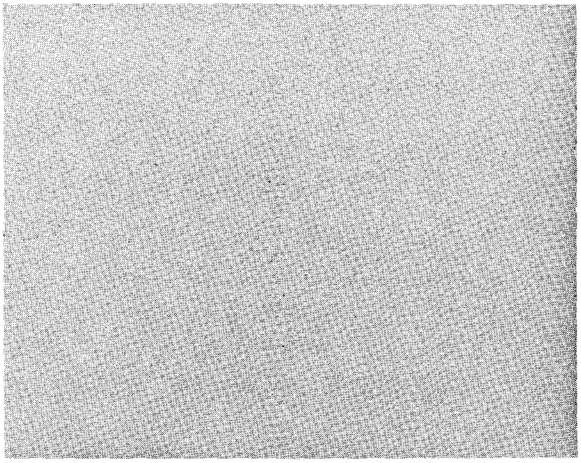
The programme material used in these tests comprised excerpts from each of the items of an evening's entertainment and included pictures from image-orthicon, C.P.S. Emitron and Vidicon studios, news film, telerecordings, etc. Only television engineers, experienced in subjective testing, were used as observers and the panel consisted of twelve persons taken in three groups. They were shown the incoming picture on one 21-inch (53 cm) picture monitor, while the standards converted picture was displayed on a similar monitor alongside: they were asked to mark the picture quality of both pictures on a six-point scale:

1. Excellent
2. Good
3. Fair
4. Rather poor
5. Poor
6. Unusable

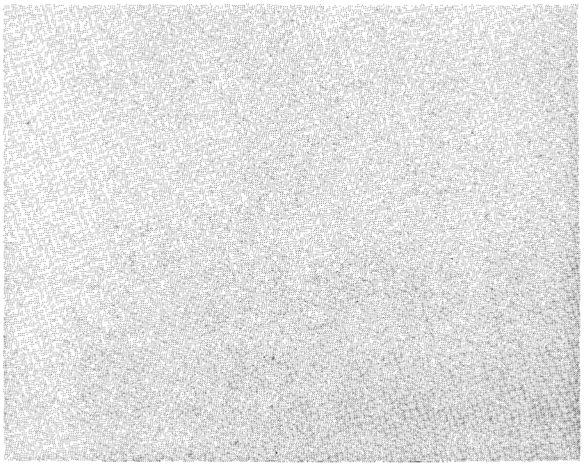
They were also asked to mark the *difference between the two pictures* on the following scale:

1. Not perceptible
2. Just perceptible
3. Definitely perceptible
4. Somewhat objectionable
5. Definitely objectionable
6. Unusable

The tests were conducted with both input and output standards of 405 lines, 50 fields per second (nominal) and in the main tests the phase of the 'reading' (camera-tube) beam was adjusted for greatest freedom from multiple imaging, i.e., just in advance of the 'writing' cathode-ray tube beam. It was established separately that the decay time constants of the Ferranti tube were sufficiently long to avoid brightness-modulation difficulties as a result of an 0·25 c/s field frequency difference.



(a) Ferranti 9/24/DXM



(b) Fernseh BMP 10/9

Fig. 19 - Phosphor grain photographs x 5 magnification display tubes not yet in service

The Vidicon camera tube was not tested because suitable apparatus was not available. A very high-quality display system is required to produce a good picture on the small Fernseh tube, which alone has sufficient screen brightness to operate the Vidicon as a standards converter. The erasure characteristics given for the Vidicon in Fig. 13 are exceptionally good: they can be obtained with the E.M.I. 10667(S) Vidicon tube when it is operated under very favourable circumstances. Any attempt to make subjective appraisals by means of a crude laboratory arrangement would, in this case, produce misleading results. The performance of the P.812, close-spaced, image orthicon is very similar to the best vidicon in respect of erasure and if the movement portrayal of the latter could be regarded as satisfactory it would be essential to examine the Vidicon in more detail.

6.2. Results

The reader who has examined the measured erasure characteristics shown in Fig. 13, the resolution results of Fig. 12 and has considered the signal-to-noise

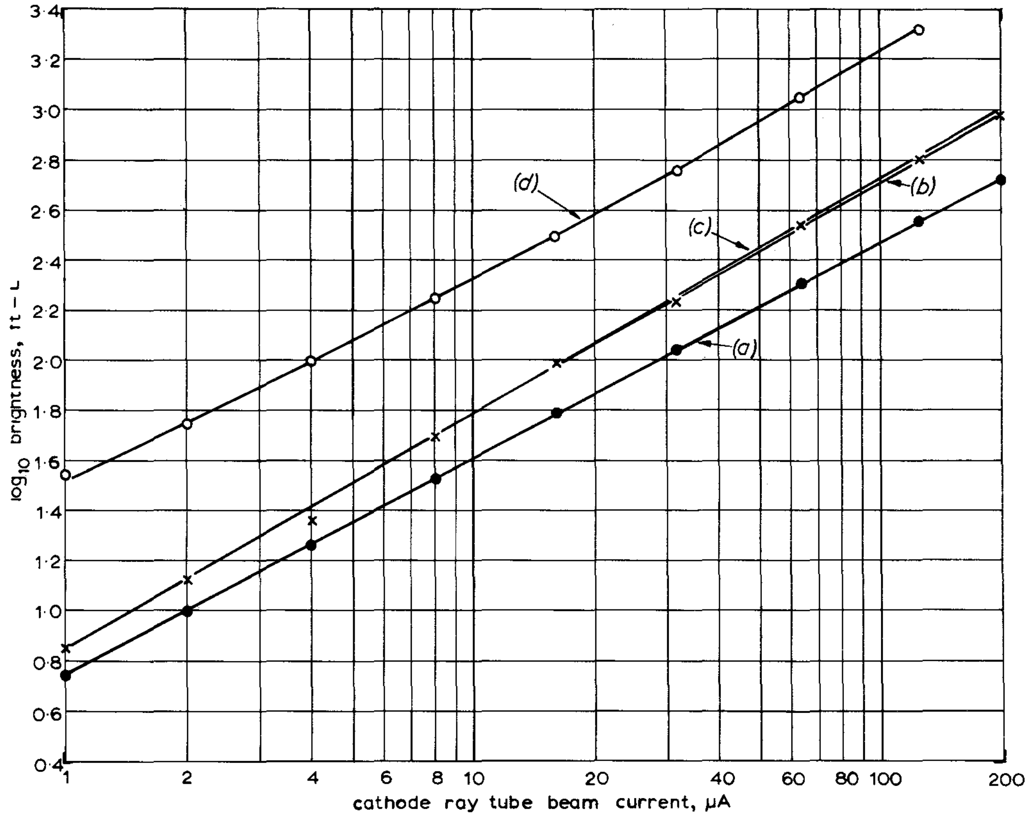


Fig. 20 - Brightness of Willemite Phosphors for given beam currents

(a) - Ferranti 9/24/DM e.h.t. 25kV, raster size 12 x 9cm
(b) - Cintel C106/J2F e.h.t. 25kV, raster size 12 x 9cm
(c) - Ferranti 9B/24/D2M e.h.t. 25kV, raster size 12 x 9cm
(d) - Fernseh BMP 10/9 e.h.t. 25kV, raster size 6·4 x 4·8cm

ratio measurements summarized in Table 1, will probably not be surprised to learn that the panel of observers taking part in the subjective tests, described in this section of the report, found the C.P.S. Emitron to be the most satisfactory camera tube for standards conversion. The same choice was made in 1959 when this tube was selected for the Television Centre converters which are used principally for conversions between 525 lines, 60 fields/sec and 405 lines, 50 fields/sec.

The average markings of the three tests were as follows:

TABLE 2

Mean subjective gradings - unconverted and converted pictures

	INCOMING PICTURE	STANDARDS CONVERTED PICTURE
C.P.S. Emitron	2·00	2·36
P.812 Image Orthicon	2·24	2·88
P.822 Image Orthicon	2·21	3·34

where 1 is Excellent 3 is Fair
2 is Good 4 is Rather Poor

The differences between incoming and converted pictures were marked as follows:

TABLE 3

Mean subjective difference gradings

C.P.S. Emitron	1·94
P.812 Image Orthicon	2·23
P.822 Image Orthicon	2·83

where 1 is Imperceptible difference 2 is Just perceptible difference
3 is Definitely perceptible difference

It is thought that the six-point scales used for these tests were perhaps rather coarse for resolving the performance variations and care is necessary in interpreting the numerical differences.

The arrangement of the four possible causes of picture degradation were of particular significance.

TABLE 4

Causes of degradation

	P.822 IMAGE ORTHICON	P.812 IMAGE ORTHICON	C.P.S. EMITRON
Worst feature	Noise	Movement	Movement
Second feature	Resolution	Resolution	Resolution
Third feature	Background	Background	Background
Least-criticised feature	Movement	Noise	Noise

The P.822 image orthicon provoked almost unanimous complaint that noise was the cause of the degradation: the other 'features', i.e., movement errors, background and resolution stimulated very little adverse comment.

The P.812 image orthicon was largely criticised for its movement portrayal, although with not quite the same unanimity as for noise in the P.822.

The C.P.S. Emitron had no single feature which caused a substantial majority of all complaints. The worst feature was movement portrayal, but this was not criticized to anything like the same extent as it was in the P.812 image orthicon. All three tubes caused an approximately equal degree of criticism as regards resolution. This was to be expected since, in each case, equalization was adjusted to give the same result on a test card.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Limits of Acceptable Performance

Correlation of the result of the subjective appraisals with the measured performance of the apparatus makes it possible to establish approximately the thresholds of acceptability for random noise and movement error. The principal criticisms which have been made concerning the present operational standards converters are largely confirmed in the laboratory experiments.

7.1.1. Movement Portrayal

Those camera tubes which have an erasure characteristic such that there is a faintly visible television image after eight or ten scans have followed the extinction of the optical image, are not regarded as satisfactory as regards movement portrayal. The distance that can be moved by an object during this period may be sufficiently great to make it appear to be followed by a 'smear' which also has the effect of obliterating detail of the object itself. Where, as in the type P.822, medium-spaced, image orthicon there is no measurable remanent television image after the fourth scan, although the outputs on second and third scans may be quite substantial, there was no criticism of movement portrayal.

This indicates that the double image which may arise from certain phase conditions between 'writing' and 'reading' beams, or the images due to cathode-ray-tube persistence, are less likely to make matters very much worse in cases where the camera tube efficiently erases stored information in the first three or four scans. Where, however, the camera tube produces a visible trail of ten or more separate, remanent images, each of these will, in turn, be similar to an original, which was, itself, a double- or triple-image.

The P.822 4½-inch image orthicon is excellent for movement portrayal; its output during the fourth scan after extinction of the image is less than one half that given during the corresponding tenth scan of either the type P.812 image orthicon or the Vidicon, neither of which can be regarded as satisfactory. The C.P.S. Emitron is acceptable, but has some tendency to show an objectionable long 'tail' in its erasure characteristic, although the level of the remanent signals is very low indeed.

For 50 fields/sec to 50 fields/sec conversion the cathode-ray tubes in general use have afterglow durations which are longer than is desirable. Sufficient freedom from brightness modulation difficulties can be obtained with a shorter persistence and although the display is not the principal contributor to serious movement portrayal errors, some improvement could be gained by a change of the phosphor material used.

7.1.2. Random Noise

With the average quality incoming picture, noise added by the standards converter becomes somewhat objectionable (if the spectrum is substantially that of 'white' noise) where the peak signal-to-r.m.s. noise ratio is less than about 41 dB. The C.P.S. Emitron and the Vidicon produce low-level signals from a high source impedance and when the necessary corrections for shunt-capacity effects have been made, the spectrum of the noise is such that the level of the noise rises with frequency. It has long been acknowledged that the visibility of this form of noise is less than that of uniform spectrum noise having the same r.m.s. value and an allowance of 5 dB has been regarded as reasonable. It follows from the foregoing remarks and a reference to Table 1 that the P.812 image orthicon, C.P.S. Emitron and Vidicon are all satisfactory for noise, but the P.822 image orthicon is unlikely to be acceptable unless some band-limiting and 'crispening' arrangement can be contrived to bring about a substantial reduction in the noise visibility.

7.1.3. Background

The addition of static patterns due to grain and blemishes has hitherto been one of the major defects of standards conversion. It is principally due to the phosphor screen of the cathode-ray tube display, although occasionally a poor camera tube contributes further degradation. The position of gamma-correction circuits, and the degree of correction applied for aperture losses also influence the visibility of grain in the converted picture.

New techniques in the deposition of phosphors have been developed by tube manufacturers and these will reduce the difficulty in future. The new 9-inch (23 cm) Ferranti tube has an acceptable background, whereas the original tube was very poor in this respect. Cintel tubes in use at Tolsford Hill are fairly good, but the manufacturers state that an improved screen is now becoming available.

On the evidence of the one display tube measured, the Fernseh converter will suffer from somewhat worse grain than those using the larger tubes. The absolute granularity of the phosphor is slightly worse than that used in either the Cintel or the new Ferranti 9-inch (23 cm) tube and this must be coupled with the fact that the Fernseh tube is only 4 inch (10 cm) in diameter, so that the linear magnification of grain size in the final picture will be more than twice as great.

7.1.4. Resolution

The overall resolution of an image-transfer standards converter is, of course, dependent on the performance of the display, the optical system, and the camera tube. The use of equalization in the camera permits an improvement in resolution at the cost of increased visibility of noise, but this process can only be used to a very limited extent and it is most desirable that losses in the display and optical system should be reduced to the absolute minimum.

Appraisal of existing equipments gives the impression that the displays used for standards conversion do not give the best performance that can be achieved with currently-available components and that some improvement in both design and operation is called for.

7.1.5. Sensitivity

The sensitivity of the P.822 image orthicon is about three times that of the P.812 image orthicon and about twelve times that of the C.P.S. Emitron, see Fig. 11. The latter can, however, be adequately exposed with a display brightness well within the capability of the 9-inch (23 cm) cathode-ray tube (about 50 ft-L (538 asb)) and, therefore, none of these camera tubes is handicapped on this account. The Vidicon is capable of operation over a very wide range of input illuminations but its erasure characteristic is dependent on the mode of operation and it is only by using incident photo-cathode illumination two hundred times greater than that required by the P.822 image orthicon that the erasure mentioned earlier can be achieved. Even with the aid of a wide-aperture lens, it is desirable to operate the cathode-ray tube at a brightness in excess of 1500 ft-Lamberts (16000 asb) and, therefore, the special high-brightness Fernseh tube must be used for this purpose. This tube performs remarkably well under such difficult requirements.

7.1.6. 'Sticking'

The requirement for freedom from 'sticking' in image orthicons is much more stringent in a standards converter than it is in ordinary studio use, since the input picture is not under the control of the operators. A suitable specification cannot be met by image orthicons in current use, and sticking has always been one of the principal difficulties with converters using them. Fortunately, the experimental 'stick-resistant' image orthicon examined during these tests promises that this need not be a problem in the future: it also seems that the advantage will be gained without loss in other respects, for the experimental tube is in no way inferior to the normal type P.812. The new target material must be considered an essential feature for image orthicons used in standards converters.

7.2. General Recommendations

7.2.1. Camera tubes

Largely because the C.P.S. Emitron has no serious disadvantage, and is a good 'all-rounder', it is found to be the best tube currently available for standards conversion and is, moreover, a simple tube to set up and operate.

It is unfortunate that neither of the current types of 4½-inch image orthicons is suitable for standards conversion. The P.822, medium-spaced tube adds too much noise to an incoming picture whose signal-to-noise ratio is already of marginal acceptability, and the movement portrayal of the P.812, close-spaced tube (like that of the Vidicon) is such that it would not be acceptable for the standards conversion of a complete programme service. A point in favour of the image orthicon is, however, that it is familiar to many operational staff and there is a selection of highly developed camera channels in which it may be accommodated.

In standards converters already using the 4½-inch image orthicon, serious consideration should be given to a few possible improvements.

(a) Reliable means for checking the erasure performance must be provided, and operational instructions for frequent routine checks should prevent the recurrence of serious movement error due to the use of worn-out camera tubes.

(b) The possibility of using the type P.822 image orthicon with its excellent movement portrayal should be studied. It can only be made acceptable by special measures to reduce the noise visibility and even then the performance in this respect may be marginal. Suggested possibilities are, redistribution of noise in the grey scale by introducing part of the gamma correction after the conversion camera, operation at higher target potentials with light-input and/or beam current limitation, and adjustment of the frequency-spectrum of the output noise with possible 'crispening' of the signal.

(c) The possibility of yet another intermediate spacing between target and target-mesh of the image orthicon is already being discussed with the manufacturers. It is noteworthy that an alteration in this spacing of

> only 0·001 inch (0·025 mm), which must be considered a close mechanical tolerance in this application, produces a change of characteristic from 'good movement with bad noise' to precisely the reverse. Although the manufacturing control of these tubes is remarkably good, small variations in the spacing between target and target-mesh of tubes labelled with a given type number may be detected by studies of the light transfer characteristic, sensitivity and signal-to-noise ratio: it may be possible that a tube with somewhat greater spacing than that of the P.812, yet less than that of the P.822, could by manufacture, or even by selection from present production, fulfil the requirement better than either of the two listed types.

The inclusion of the 'stick-resistant' target material must be considered essential.

7.2.2. Display Tubes

The cathode-ray tube display used in image-transfer standards converters merits much closer attention than it appears to have received so far. Resolution lost in the optical part of the channel can only be regained, in part, by complicated electrical pre-equalization techniques, and every effort should be made to minimize such losses.

The 9-inch (23 cm) display tube is sufficiently large compared with a normal photo-cathode to be optically efficient; envelopes of this type are, moreover, usually of much better quality than those of larger size since they are intended only for broadcasting purposes and are therefore to be recommended. Ferranti Ltd. have demonstrated their ability to produce tubes of this size with an extremely uniform phosphor screen.

The afterglow of the phosphor could, with advantage, be reduced to about half the present duration. This would bring about some improvement in movement portrayal by those camera tubes which suffer significantly from this defect but it would not be sufficiently short to give rise to brightness-modulation difficulties in asynchronous operation. If it were possible to obtain phosphors having afterglow characteristics nearer to the form of a single exponential brightness decay characteristic, rather than the sum of several exponentials having short and long time-constants, this, too, would assist in movement portrayal. Sufficient cancellation of photo-signal troubles in the C.P.S. Emitron due to the use of shorter afterglows can be achieved by means of a special circuit arrangement.

The existence of a phosphor having the afterglow characteristic required, together with the necessary freedom from visible granularity, has yet to be demonstrated. This must be investigated and discussed with the appropriate manufacturers.

7.2.3. Circuit Arrangement

The location of the correction circuits for aperture losses and 'gamma law' in the video chain of the standards converter is dependent on the camera tube used and its worst features. If long trails of low-level multiple images cause severe movement-portrayal difficulties, then gamma correction after the camera tube is to be avoided since a greater amplification in the dark tones of the picture will increase their visibility. If noise is the chief difficulty, then a study of Research Department Report No. T-092[12] may indicate the usefulness of some 'black stretch' in the converter camera channel, the remainder of the correction being placed in the video circuits before the display. Pre-emphasis of the upper video frequencies in the incoming signal before the display certainly seems to be a desirable feature, and the smaller the degree of aperture correction necessary in the camera channel, the less will be the visibility of noise in the converted picture.

Vertical aperture correction should be included in the display of the standards converter. A considerable improvement in the subjective sharpness of the picture can be obtained by arranging an optimum balance between the vertical and horizontal corrections which may be applied for a given visibility of noise.

7.2.4. Operational

There is clearly a need for some test equipment in connection with image-transfer standards converters. An electronically-generated moving bar is most valuable in checking for excessive multiple-image production, and some standby signal which does not impress itself permanently on either the display tube or the camera is very desirable. It is necessary for a display to be available when the apparatus is not 'on the air', but the use of fixed patterns, such as Test Card 'C', should be avoided. Possibly the two requirements should be combined in a unit designed to produce an electronically-generated pattern which, in order to avoid 'sticking', moves through the picture continuously when the converter is on standby yet moves slowly enough to provide facilities for level and grey-scale checking. The instrumentation could be such that the unit also produced the high-contrast bar required to check motion portrayal at various object velocities.

Finally, more attention could be given to the mechanical and electrical controls of the apparatus. It should be possible, for example, for the operator to see the display clearly and at close range while carrying out all adjustments affecting the picture quality. It is also desirable that as many adjustments as possible are on knobs with dial settings which can be logged, since there has been a noticeable reluctance on the part of the average operator to 'burn his boats' by irretrievably abandoning settings which give a passable if not optimum result.

8. ACKNOWLEDGEMENTS

This report is the result of work carried out by several members of Image Scanning Section. In particular, J.R. Sanders was responsible for the measurements of camera-tube characteristics and the survey of existing standards-conversion apparatus; C.J. Dalton investigated the properties of cathode-ray tubes and both S.M. Edwardson and J.R. Sanders assisted in the formulation of the conclusions and recommendations.

The assistance of Mr. B.S. Pover, Tel. O. and M. (L.S.) in providing information concerning operation of the Vidicon camera tube and that of Mr. R. Thomas, Tel. O. and M. (R. and O.B.) in carrying out tests and investigations at Tolsford Hill, are gratefully acknowledged.

9. REFERENCES

1. 'An Outline of Synchronous Standards Conversion Using a Delay Line Interpolator', Research Department Report No. T-096, Serial No. 1962/31.
2. Rainger, P., 'A New System of Standards Conversion', International Television Conference Digest 1962.
3. 'Specification of Monochrome and Colour Television Standards for 625-Line Experimental Transmissions', BBC Engineering Division.
4. Lord, A.V., 'A Standards Converter for Television Exchange Between Europe and North America', E.B.U. Review, Part A, No. 63, October 1960.
5. 'Vertical Resolution and Line Broadening', Research Department Report No. T-082, Serial No. 1962/15.
6. Lord, A.V. and Rout, E.R., 'A Review of Television Standards Conversion', International Television Conference Digest, 1962, Research Department Report (in preparation).
7. Brit. Pat. App. 28036/62.
8. Brit. Pat. 722962, 1952.
9. Sarsen, A.E. and Stock, P.B., 'A New Approach to Telerecording', British Kinematography, Vol. 31, p. 119, 1957.
10. Gibson, W.G. and Schroeder, A.C., 'A Vertical Aperture Equalizer for Television', J.S.M.P.T.E., Vol. 69, No. 6, June 1960.
11. Hughes, W.L., 'Minimizing the Effects of Vidicon Lag with a Long Video Delay Line', I.R.E. International Convention Record, Part 7, 1961.
12. 'The Variation in the Visibility of Interference Over the Grey Scale of a Television Picture', Research Department Report No. T-092, Serial No. 1962/27.
13. 'A Comparison of Two Flare-Reducing Methods in Conventional Cathode-Ray Tubes', Research Department Report No. T-075, Serial No. 1960/19.
14. Worswick, T., 'The BBC Television Standards Converter', J.S.M.P.T.E., Vol. 68, No. 3, March 1959.
15. Rout, E.R. and Vigurs, R.F., 'A Wide-Range Standards Converter', J. Tel. Soc., Vol. 9, No. 12, October/December 1961.
16. 'An Assessment of the Marconi Standards Converter', Research Department Technical Memorandum No. T-1042.
17. 'The Fernseh Standards Converter', BBC Engineering Division Report No. A-074, Serial No. 1962/38.